## Description

# Reactor for Performing a Strongly Heat-Conditioned Catalytic Reaction

The invention relates to a reactor for performing heat-conditioned catalytic reaction within a process fluid, equipped with plates that are arranged parallel to one another at a distance to form flat channels with lateral boundary areas that face one another, whereby a portion of the channels contain a solid catalyst and carry the process fluid, and another portion of the channels guide a heat transfer medium in indirect heat contact with the process fluid.

## Background of the Invention

Catalytic processes are often connected with high energy conversions. In most cases, a specific temperature range must be maintained to achieve a high conversion and high yield of desirable products (selectivity,) and to avoid damaging the catalyst that is used. Adiabatic reactors with intermediate cooling result in a considerable number of components or in a reactor of expensive design. Solid-bed reactors with cooling and heating devices in the bed are also known. In most cases, these are tubular reactors with a solid bed and with heat-transfer-medium-guiding tubes in the solid bed, as they are described in all standard works on reaction technology, for example in Ullmann's

Encyclopedia of Industrial Chemistry, VCH 1992, Vol. 4B. A reactor with coiled coolant tubes in a solid bed is disclosed in M. Lehmbeck's "Linde Isothermal Reactor for Methanol Synthesis" 41 (1986), pages 5 to 8.

A tube reactor with catalyst particles in the tubes is known from the journal Hydrocarbon Processing, March 1997, page 134. The tubes are cooled on the jacket side of the reactor with boiling water or other suitable heat transfer media. The division of the reaction chamber and the catalyst particles in several tubes guarantees that in the case of a malfunction, a self-accelerating reaction, caused by local superheating, is limited to a reaction tube and does not extend to the entire reactor. The reactor design has proven its value, but it also exhibits several drawbacks.

-- In practice, the reactor jacket must often be designed for high coolant pressure. As a result, the jacket is very thick and thus costly, and the reactor is difficult to transport.

-- In the case of a large diameter, the tube bottoms are also very thick and jeopardized by thermal stress.

-- The many reaction tubes can be filled only at great expense. In particular, attention must be paid to uniform filling with equal pressure loss in the various tubes, so that a sparingly

loaded reaction tube because of a large pressure drop does not become overheated.

-- Because of the high weight, in most cases C-steel is used, although rust is thus unavoidable. For many reactions, however, rust acts as a catalyst poison.

A plate heat exchanger with a catalyst solid bed is known from DE 198 04 806 A1. It contains cooled separating walls in the bed. The reactor jacket must be designed only for the pressure of the reaction gas; the reactor requires no tube bottoms. It is thus lighter overall than a tube reactor and therefore can also be made from high-grade steel at lower cost.

A prior art reactor closely related to the present invention is disclosed in Patent US 3,528,783. Rectangular channels formed with bent sheets direct, on the one hand, a reaction medium and, on the other hand, a heat transfer medium. The channels through which the reaction medium flows contain solid catalyst material. These channels are sandwich-like positioned between channels through which the heat transfer medium flows.

The drawback to this multi-layer catalytic reactor -- as also to other catalytic-bed reactors -- is that during operation a temperature profile forms in the channels that contain the catalyst material crosswise to the direction of flow of the reaction medium. As a result, only an average temperature can be set. An optimal conversion and an optimal selectivity can

therefore not be achieved in principle. In addition, a local superheating of the catalyst material and an overflowing of the reaction in a way that is undesirable or even hazardous cannot be ruled out. In addition, the above-mentioned multi-layer reactor has the drawback that it requires a pressure-resistant outer container.

## Summary of the Invention

An object of the invention is therefore to avoid the above-mentioned drawbacks.

Upon further study of the specification and appended claims, further objects and advantages of this invention will become apparent to those skilled in the art.

These objects are achieved according to the invention by a reactor comprising plates that are arranged parallel to one another at a distance and form flat channels with lateral boundary areas that face one another. A portion of the channels contain a solid catalyst and carry a process fluid, and another portion of the channels guide a heat transfer medium in indirect heat contact with the process fluid. The plates are flat or are provided with grooves or ribs and are coated at least partially with catalyst on the surface that faces the process fluid.

A characteristic feature of the invention is that the plates are flat, or are provided with grooves or ribs, and are coated at least partially with the catalyst on the surface that faces the process fluid. With the

reactor according to the invention, a significant temperature profile cannot form crosswise to the direction of flow, since the heat input or output always takes the shortest path, namely through the plates and the layer that is applied to the plates. In addition, a uniform flow through all of the channels is achieved even more readily than in catalytic-bed channels (or tubes). Also, in the case of only partial coating with catalyst, heat transfer zones can be formed in parts of the reactor which do not also provide catalytic reaction.

In an embodiment of the reactor according to the invention, advantageously the lateral boundary areas can be designed as jacket pieces, which form a pressure-resistant cuboid block with channels formed by the plates and collectors for the process fluid and for the heat transfer medium. An advantage of this embodiment is that the reactor can be operated, both on the process fluid side and on the heat transfer medium side, at operating pressures of more than 25 bar.

The channels that carry the process fluid can contain corrugated and pleated sheets (fins) that form passages for the process fluid. The heat transfer between the process fluid and the heat transfer medium is improved by the fins.

The fins can be perforated and thus form flow connections between the passages.

The fins can be coated on both sides at least partially with catalyst material. With the thickness of

the coating being the same, in this way a more effective catalyst surface is installed per reactor volume. The width of the passages for process fluid formed by the coated fins is preferably about 0.5-5 mm.

The catalyst layer can contain a support medium.

The catalyst layer can have a layer thickness of, for example, 1 to 500 µm, preferably 10 to 100 µm.

The distance between plates (without catalyst coating) is preferably about 2.5-20 mm.

The reactor according to the invention can be made of aluminum, steel or high-grade steel.

The reactor according to the invention is used especially advantageously when an endothermic reaction or an exothermic reaction is performed in the reactor. Without limiting the usability of the reactor, the following are examples of processes in which the reactor can be used.

The reactor according to the invention can advantageously be used in:

-- Synthesis of methanol,
-- Synthesis of higher alcohols,
-- Hydrogenation of hydrocarbons,
-- Selective hydrogenation of $C_2H_2$ to $C_2H_4$,
-- Non-selective hydrogenation of $C_2H_4$ to $C_2H_6$,
-- Methanation or synthesis of methane,
-- Carbon monoxide conversion,
-- Fischer-Tropsch synthesis,
-- Epoxidation,

- -- Synthesis of ethylene oxide,
- -- Claus reaction,
- -- Direct oxidation of $H_2S$ to sulfur,
- -- Oxidation of $SO_2$ to $SO_3$
- -- or in $NH_3$ synthesis.

**Brief Description of the Drawings**

Various other features and attendant advantages of the present invention will be more fully appreciated as the same becomes better understood when considered in conjunction with the accompanying drawing. Figure 1 shows a reactor according to the invention in three-dimensional representation.

In the foregoing and in the following examples, all temperatures are set forth uncorrected in degrees Celsius; and, unless otherwise indicated, all parts and percentages are by weight.

The entire disclosure of all applications, patents and publications, cited above and below, and of corresponding German Application No. 100 40 209.7, filed August 17, 2000, is hereby incorporated by reference.

**Example**

In a selective hydrogenation of acetylene to ethylene with a reactor according to the invention, with fins, operated under the following parameters

Pressure 31 bar

| | |
|---|---|
| Temperature | 70-80°C |
| Throughput | 170,000 kg/h |

and with use of liquid butane for cooling, a reactor with a volume of 13 $m^3$ can be used

| | |
|---|---|
| Length | 6 m |
| Width | 1.2 m |
| Depth | 1.8 m |
| Weight without catalyst | 16 t |

The catalyst-coated channels have a pressure drop of about 150 mbar. A comparable reactor according to the prior art has a volume that is greater by a factor of 4 to 10.

The catalyst can comprise a noble metal, e.g., palladdium, and a support material, e.g., aluminum oxide. The catalyst layer can be applied as a coating, e.g., a washcoat. See, e.g., Handbook of Heterogeneous Catalysis, Vol. 14, 11 Environmental Catalysis - Mobile Sources, pp. 1572-83. The catalyst layer can also be applied by chemical vapor deposition (CVD)as described, e.g., in the Handbook of Heterogeneous Catalysis, Vol. 2, pp. 853-55.

The invention is explained in more detail in conjunction with the following description of Figure 1 which illustrates an embodiment of the invention.

The principle design of such a reactor is diagrammatically represented in the figure. The function

of the reactor is described based on the example of the selective hydrogenation of acetylene to ethylene.

Plates 1 that are arranged parallel to one another at a distance and form channels 2, for a process fluid, and channels 3, for a cooling medium, with lateral boundary areas that face one another. The boundary areas can be designed as plates 4 (shown as broken lines in the figure) or as webs 5 between plates 1 and/or (not shown in the figure) between fins and plates 1. The plate surfaces inside of the channels that guide the process fluid are coated with catalyst material 6. Not shown in the figure are collectors for the process fluid and the cooling medium, which together with the plates form a dimensionally stable and pressure-resistant reactor 7.

An acetylene-containing flow 8 is fed to, for example, reactor 7. In channels 2, the acetylene is hydrogenated to ethylene in the presence of catalyst material 6, and a flow 9 containing ethylene is obtained. Process heat that is formed as a result of the catalytic reaction is withdrawn from the plates by the flow of liquid butane 10, which is fed to channels 3. As heat is taken up, the butane is evaporated and withdrawn as a gaseous flow 11.

By removing heat right at the point of origin, secondary reactions such as formation of ethane or oligomers (e.g., anthracene oil, green oil) are largely avoided. Thus, by the more reliable operation of the

reactor according to the invention, a high ethylene yield is achieved.

The preceding examples can be repeated with similar success by substituting the generically or specifically described reactants and/or operating conditions of this invention for those used in the preceding examples.

From the foregoing description, one skilled in the art can easily ascertain the essential characteristics of this invention and, without departing from the spirit and scope thereof, can make various changes and modifications of the invention to adapt it to various usages and conditions.